U. S. FOREST SERVICE
RESEARCH PAPER INT-48
1968

High-Temperature Drying of Lumber--a Review

by

David P. Lowery, John P. Krier, and Robert A. Hann

INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION
OGDEN, UTAH

THE AUTHORS

DAVID P. LOWERY has been engaged in forest products utilization research since 1957 when he was reassigned as a Forest Products Technologist to the Intermountain Forest and Range Experiment Station from the U.S. Forest Products Laboratory in Madison, Wisconsin. During this period, he has published several reports. His project headquarters is now in Missoula, Montana.

DR. JOHN P. KRIER is Professor of Wood Technology in the School of Forestry at the University of Montana, where he has taught since 1953 and now directs student research projects on wood drying. He has published numerous articles on this subject.

DR. ROBERT A. HANN, supervisory research forest products technologist, currently heads up the section on wood drying, Division of Solid Wood Products Research, at the U.S. Forest Products Laboratory in Madison, Wis. He joined the Laboratory staff in 1957 and has conducted research on particle board and glued products before assuming his present duties.

A native of Milan, Michigan, Hann earned B.S. and M.S. degrees in wood technology at the University of Michigan. During the 1959-60 academic year, he was granted a fellowship at North Carolina State College and was awarded a Ph.D. degree in wood technology from that institution in 1965.

U.S. Forest Service
Research Paper INT-48
1968

HIGH-TEMPERATURE DRYING OF LUMBER--A REVIEW

by

David P. Lowery
John P. Krier
Robert A. Hann

INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
Forest Service
U.S. Department of Agriculture
Ogden, Utah 84401
Joseph F. Pechanec, Director

HIGH-TEMPERATURE DRYING OF LUMBER--A REVIEW

The worldwide research effort devoted to the high-temperature drying of wood has contributed greatly to our understanding of this process. However, the pertinent information is so widely scattered that much of it may be inaccessible to many persons.

The object of this report is to summarize present knowledge on the convective high-temperature drying of lumber and to indicate existing gaps in this knowledge. A report entitled "Bibliography of high-temperature drying of lumber" (26)[1] lists practically all of the publications on which the present report is based. The drying of veneer and high-temperature drying using other methods of heat transfer, such as hot platens, hot oil, and high-frequency energy are not discussed.

The term "high-temperature drying" when applied to the drying of lumber includes two processes carried out with the dry-bulb temperature above the boiling point of water. In one, the superheated steam process, the wet-bulb temperature is maintained at 212° F. (100° C.), and air is excluded. In the other, a mixture of air and steam is used and the wet-bulb temperature is below 212° F. (100° C.). The present commercial practice in this country is to use a mixture of air and steam; however, this process is based on earlier use of superheated steam as the drying medium.

HISTORICAL DEVELOPMENT

An early patent for an "Apparatus for drying and seasoning lumber by superheated steam" was granted to C. F. Allen and Luther W. Campbell (2) in 1867. The use of superheated steam was proposed again in 1875 by Bulygin (1) of Russia; in 1897 by Möller and Pfeiffer (29) in Germany; and in 1918 by Tiemann (36) of this country. As a result of Tiemann's work, a few superheated steam kilns were installed and operated in the Pacific Northwest for the commercial drying of softwoods. These kilns did not contain fans, instead circulation was achieved by steam jets. Rapid deterioration and high maintenance costs of the kilns forced their abandonment.

According to Egner (7), dry kilns capable of operating in the high-temperature range were available in a few European countries in 1930. These kilns corroded excessively and did not produce quality material, especially with green hardwood species.

[1] Numbers in parentheses refer to Literature Cited at end of this paper.

Fischer and Czepek (9) pioneered development of the present-day high-temperature dry kilns during 1939 to 1944 when they carried out a number of experiments using small electrically heated kilns. Fans provided air circulation and the test material was heated in a saturated atmosphere before the drying process was started. They achieved astonishingly short drying times for coniferous species at temperatures of 248° F. (120° C.). After World War II, other German scientists studied hot-air drying and developed commercial equipment based upon the work of Fischer and Czepek.

FUNDAMENTAL ASPECTS

High-temperature drying, as practiced today, is fundamentally no different than kiln drying at any other temperature. It is simply a batch-type, forced convection drying process. However, the relative importance of various parameters changes with temperature and failure to recognize these changes has led to some confusion about high-temperature drying.

The Stages of Drying

Several investigators have observed two or three stages in high-temperature drying. These stages have been based on the drying rate and the wood temperature. Kollmann and Schneider (20) present an excellent summary of three stages.

The first stage of drying--the constant rate period--occurs only if the initial moisture content of the wood is above the fiber-saturation point. Evaporation takes place at the surface and the drying rate depends only on the external drying conditions--temperature, relative steam content, and the velocity of the drying medium. The drying rate can be calculated by using the rate of heat transfer, because heat and mass transfer must be equal during the constant rate period. The length of time during which constant rate drying takes place depends on the ability of the wood to supply liquid to the surface.

During the constant rate period, the wood temperature does not exceed the wet-bulb temperature, 212° F., in pure steam at atmospheric pressure.

When the wood can no longer supply water so that free water is present over all of the surface, the drying rate slows down and surface temperature starts to rise above wet-bulb temperature. This marks the beginning of the second stage of drying, frequently called the falling rate period.

Heat transfer into the wood and vapor movement out of the wood control the drying rate. It is believed that a zone of evaporation is formed inside the wood and that this zone moves from the surface toward the interior as drying proceeds. The increasing distance from the surface increases the resistance to heat and moisture flow, explaining the falling rate that is observed. The temperature and pressure at various depths inside the wood will depend on the relative ease of heat and mass transfer and the moisture content at the depth of interest.

When the wettest portion of the wood falls below the fiber-saturation point, the third stage of drying begins. This is also a falling rate period. The third stage continues until all of the wood is in equilibrium with the drying atmosphere.

The second and third stages are discussed in detail by Kollman and Schneider (20) and Hann (11).

Moisture Movement

Tiemann (37) pointed out that the quickest way to remove free water from wood is to heat the material above the boiling temperature. The free water than vaporizes as rapidly as the necessary heat is supplied to the wood. However, the hygroscopic moisture cannot be boiled off and evaporation will be much slower below the fiber-saturation point. Tiemann also stated that the temperature in the wood could not exceed 212° F. as long as free water existed if the drying was done at atmospheric pressure. After the free water has vaporized, the material temperature will begin to rise until ultimately it attains the temperature of the superheated steam. He failed to state, but undoubtedly realized, that the pressure in the wood also could not exceed atmospheric pressure if the temperature in the wood stayed at 212° F. when free water was present.

Tiemann pointed out that the evaporative capacity of the superheated steam is dependent upon the amount of steam contacting the lumber and the number of degrees the steam is superheated. If the drying rate is slow enough, free water will be brought to the surface by capillary flow; however, if the drying rate is too rapid, the continuity of the capillaries will be broken and free water flow to the surface will cease. After capillary waterflow ceases, water-vapor diffusion becomes the only means by which moisture can move from the interior to the surface. The chief disadvantages to the use of superheated steam are the extreme speed with which it loses its superheat and becomes saturated and the large amount of energy required to heat the lumber.

However, Czepek (6) states that when wood is heated above 212° F. vapor diffusion occurs and there is almost no capillary movement of moisture. The movement of water vapor from inside to outside is also facilitated by the vapor pressure gradient as it relates to the drying atmosphere. He hypothesized that the flow of moisture through the wood is much greater at temperatures above 212° F. than at temperatures below 212° F.

According to Egner (7), however, moisture moves through the wood by both vapor diffusion and capillary forces. He cited temperature distribution curves obtained from wood cross sections as proof of the capillary movement of water in wood above the fiber-saturation point.

Egner also states that high-temperature drying using either superheated steam or steam-air mixtures is essentially the same as conventional drying. However, in the temperature range above 212° F. the term relative humidity should be used with reservation and he proposes the term "relative vapor content" as all humidities cannot be attained in this temperature range. He says that there is an increasing plasticity of the wood at high temperatures, which permits adjustment of some of the drying stresses. As a result, wood, so dried, fails to develop checks and other types of seasoning degrade.

Equilibrium Moisture Content

Keylwerth (13) investigated the relationship between wood moisture content and superheated steam in the temperature range above 212° F. at atmospheric pressure for spruce and beech. Also, he extrapolated the hygroscopic isobars for temperatures below 212° F. to a temperature of 266° F. The graph indicated that a temperature of 230° F. would give an

equilibrium moisture content of approximately 7 percent in pure superheated steam. He pointed out that drying by superheated steam could be controlled by the dry-bulb temperature at atmospheric pressure, because the wet-bulb temperature would always be at 212° F. He also recognized that an absolute pressure differential might exist between the interior of the wood and the surface, due to the restriction of the rate of vapor movement by wood. The existence of such a pressure differential could influence the drying rate.

Koehler (17) presented graphs of relative humidity-equilibrium moisture content for temperatures up to 212° F. Eisenmann (8) published sorption isotherms for the range above 212° F. and established that there is hygroscopic equilibrium in this range at normal atmospheric pressure. Kauman (12) also developed charts of the temperature-relative-humidity-equilibrium wood moisture content for temperatures up to 400° F.

External Mass and Energy Transfer

Kollman and Schneider (20) studied the influence of circulation rate on lumber dried in superheated steam. In order to determine how velocity influences the rate and mechanism of drying, they carried out systematic experiments with pure, superheated steam and with a steam-air mixture. Velocities ranged from 230 to 2,100 feet per minute. For the first stage of drying (constant rate period), the drying rate increased as the 0.5 to 0.6 power of the velocity. In the following stage of falling drying rate, the effect of flow velocity became steadily smaller but remained discernible to 20-percent average moisture content. Because of the high heat transfer rates needed to maintain the rapid drying rates possible in high-temperature drying, especially during the constant rate period, the flow velocity is of much greater importance than in kiln drying at normal temperatures.

EVALUATION OF HIGH-TEMPERATURE DRYING

Few studies of high-temperature drying have been of an evaluation type, although much information has been gleaned from investigations having other objectives. There is a certain risk in generalizing from knowledge obtained in the drying of a particular species under particular conditions. However, a summary of this information should be of value to those engaged in research.

ADVANTAGES

Probably the most important advantage of high-temperature drying is the speed of drying; only about one-fourth of the usual time is required (35). Thus a smaller number of high-temperature kilns would be needed to dry the same quantity of lumber, which also will give a space savings (10).

Another advantage is the savings due to reduced inventory. Material can be processed rapidly, thereby reducing overhead costs and the necessity of maintaining a large inventory in order to satisfy immediate orders. Inventory reduction would also mean a savings in space.

Keylwerth (14) has stated that the normal energy required for superheated vapor kilns is 1.2 to 1.5 kilowatt hours per kilogram (2.2 pounds) of water evaporated, while low-temperature kilns require 2 to 4 kilowatt hours per kilogram.

Sharma and Bali (33) noted a significant reduction in the shrinkage of toon--a member of the mahogany family--dried at high temperature. Tangential shrinkage was reduced more than radial shrinkage and volumetric shrinkage was not significantly different. High-temperature drying appeared to reduce shrinkage in western redcedar shingles dried below 10-percent moisture content (30).

Many investigators have reported a reduction in the equilibrium moisture content for high-temperature dried material. Koehler and Pillow (18) in 1925 compared air-dried Sitka spruce test specimens with specimens that had been exposed to 220° F. and 280° F. for periods up to 8 days. They noted a marked reduction in equilibrium moisture content in the specimens heated at 280° F., and a like reduction, though considerably smaller, in the specimens heated at 220° F. The major portion of the reduction occurred during the first 3 days of treatment and amounted to 2 percent for the material dried at 220° F. and 5.5 percent for the material dried at 280° F. Keylwerth (13) compared the equilibrium moisture content of material dried in pure steam at 240° F. with material dried at 150° F. In a normal climate, the equilibrium moisture content for the wood dried at 240° F. was 10.4 percent and for the wood dried at 150° F. was 12.2 percent.

DISADVANTAGES

The disadvantages of high-temperature drying can be grouped into two broad categories, those attributable to (a) the kiln, and (b) the quality of the dried material. Among the disadvantages attributed to commercial kilns are: higher initial cost, greater power requirement, and a greater heating capacity (16). Although no cost data are available, it has been assumed that costs for high-temperature kilns are greater because of the need for higher quality construction material to reduce heat loss and resist corrosion. In high-temperature drying, a relatively high airspeed is required to rapidly supply heat and to remove the water brought to the wood surfaces (23). Such airspeeds call for more installed power or, perhaps, the installation of additional fans, hence, greater costs. Also, greater heating capacity is necessary to quickly reach and maintain the desired high temperatures.

The quality of high-temperature-dried material entails an evaluation of the physical, mechanical, and chemical properties of the material. Probably the most obvious change in high-temperature dried wood is in the coloration. Many investigators have commented on the fact that material dried above 212° F. becomes a light brown or "toasty" color. If the material is surfaced, most of the discoloration is removed. Kollman (19) states that this discoloration is affected more by the wood moisture content and the drying humidity than by the drying temperature. Another change in physical appearance is knot dropout. Intergrown knots are not affected by temperatures above 212° F.; However, encased knots, resulting from dead branches, have a consistent tendency to drop out.

Because of the very rapid drying in high-temperature kilns, a steep moisture gradient is attained during the drying period (34, 25, 15). This severe moisture gradient and certain associated drying defects make this drying method unsuitable for the drying of many hardwoods from the green condition. However, air or predried hardwoods have been satisfactorily dried at high temperature (4). The moisture gradient may carry over in the material after it has been removed from the kiln and some of the time advantage accruing through the fast drying may be lost if the material is fully conditioned. The rapid drying and steep moisture gradient are also presumed responsible for the severe casehardening reported by Calvert (3).

It is recognized that exposure of wood to high temperatures for moderate periods of time or to moderate temperatures for long periods of time can effect a decrease in the dry weight of the wood (28). Koehler and Pillow (18) state that exposure to 280° F. for periods up to 8 days also caused a 5-percent reduction in specific gravity. Whether such a reduction in specific gravity occurs in high-temperature-dried material, where the exposure time at a temperature of 230° F. is considerably less, is not known.

Practically all of the mechanical properties of wood have been used to evaluate the effects of high-temperature drying.

Keylwerth (13) obtained higher average values for modulus of elasticity, maximum crushing strength, and modulus of rupture for the high-temperature-dried material than for the conventionally dried material. However, conventionally dried material was higher in impact strength and maximum stress in tension perpendicular to the grain. His spruce material was dried in pure steam at 240° F. This drying condition may account for the discrepancy between these results and later investigations. The control material was dried at 150° F.

Comben (5) stated that superheated steam drying had a negligible effect on the strength properties of obeche, abura, and Scots pine. Mahogany had an appreciable reduction in toughness and impact strength as well as an increase in brittleness.

Egner (7), working with spruce in Germany, obtained results that indicated high-temperature drying had no effect on the impact bending strength. Leont'ev et al. (24) tested pine dried in superheated steam at 212° F. and obtained approximately a 7-percent reduction in compression parallel to the grain, work in impact bending, and shear along the grain. In later work, Krecetov and Tsarev (22) determined that impact bending strength was reduced approximately 20 percent after exposure for 26 hours to 241° F., 28 percent after exposure to 230° F. for 28 hours, and 32 percent after exposure to 232° F. for 32 hours.

Salamon (31, 32), and Kozlik (21) have studied the effects of high-temperature drying on Douglas-fir and western hemlock. For Douglas-fir dried in superheated steam, as compared with conventionally dried Douglas-fir, Salamon obtained reductions in fiber stress at proportional limits of 5 to 16 percent, in modulus of rupture of 9 to 17 percent, in modulus of elasticity of 3 to 7 percent, and in maximum crushing strength of 8 to 13 percent. For Douglas-fir dried in an air-steam mixture, the reductions were: fiber stress at proportional limit, 7 percent; modulus of rupture, 13 percent; modulus of elasticity, 8 percent; and maximum crushing strength, 2.5 percent. Salamon obtained significantly higher values for the high-temperature dried western hemlock than for the conventionally dried western hemlock.

The values obtained by Kozlik (21) for Douglas-fir showed a 25-percent reduction in toughness for material dried at 215° F. and at 230° F. as compared to material dried at 90° F. and at 150° F. Modulus of rupture values showed a reduction of 12 percent in material dried at 90° F. as compared to material dried at 215° F. However, there was no significant difference in such values between material dried at 90° F. and material dried at 195° F. Radial and tangential shear values were reduced 15 to 20 percent for the material dried at 215° F. as compared with material dried at 90° to 150° F. Modulus of elasticity was least affected by temperature, being reduced 5 percent between material dried at 215° F. and material dried at 150° F. For western hemlock, toughness was most affected, being reduced 19 percent in tangential and 15 percent in radial toughness for specimens dried at 230° F. Modulus of rupture values were reduced 12 percent for the high-temperature-dried wood. Fiber stress at proportional

limit was slightly affected by the drying temperature, and modulus of elasticity values had a 4-percent reduction for the 230° F. compared with the 90° F. material.

Calvert (4) reported a 5-percent reduction in modulus of rupture after high-temperature drying, but no effect on toughness in red and white pine. Control material was conventionally kiln dried. For eastern hemlock, there was no difference in the modulus of rupture between the high temperature and the conventionally dried material and toughness values were greater for the high-temperature-dried specimens. Yellow birch and hard maple, high-temperature-dried, had an increase in all strength values.

In addition to mechanical tests, Egner (7) determined that high-temperature drying did not adversely affect the wear and tear (a special test) of spruce. He was able to glue satisfactorily high-temperature-dried spruce and beech, using casein, urea, melamine, phenol, and resorcinol adhesives.

The effect of high-temperature drying on the chemical makeup of wood has also been studied by Salamon (31). For western hemlock, there was no change in the lignin content and only a slight decrease in holocellulose and in the 1-percent alkali-soluble hemicellulose in high-temperature-dried material.

MacDonald and Maclean (27) determined that western redcedar shingles could be dried at 285° F. without appreciable degrade on the chemical extractives that contribute to their durability.

SUMMARY

Although the process dates back to the last half of the 19th century, the high-temperature drying of lumber has become an established commercial practice only in the last 25 years. Even today the use is limited but interest is high.

Past research has shown that the mechanism of moisture movement during the constant rate and falling rate periods is not clearly understood; that flow velocity is more important in high-temperature than in conventional drying; and that equilibrium moisture content of wood at high temperatures is lower than at room temperature.

Reported advantages of high-temperature drying include short drying times, reduced inventory, lower energy requirements, reduction in shrinkage, and a lower equilibrium moisture content in use.

Disadvantages reported are higher initial equipment cost, greater power requirements and heating capacity, discoloration of the wood, knot dropout, conditioning problems, strength loss, and greater degrade with some species.

However, all results are based on limited studies involving only one or a few species and generally not employing equipment specifically designed for high-temperature drying. The influence of flow velocity and temperature on drying rate, defects, color change, and strength loss during the various stages of drying needs to be established for various species before high-temperature drying can be fully evaluated.

LITERATURE CITED

1. Anonymous.
   1875. Artificial seasoning of timber. A. A. Press, 2d ed.

2. Allen, C. F., and L. W. Campbell.
   1867. Apparatus for drying and seasoning lumber by superheated steam. U.S. Pat. No. 64,398.

3. Calvert, W. W.
   1958. High-temperature kiln drying of lumber--a summary of eastern Canadian progress. Forest Prod. J. 8(7): 200-204.

4. ________
   1965. High-temperature kiln drying of eastern Canadian species. Can. Wood Prod. Ind., July, 6 pp.

5. Comben, A. J.
   1955. The effect of high temperature kiln drying on the strength properties of timber. Wood 20(8): 311-313.

6. Czepek, E.
   1952. Theorie and praxis der hochtemperatur holz-trocknung. Holz a. Roh-u. Werkst. 10(1): 1-6.

7. Egner, K.
   1952. Heiss Trocknung von hölzern. Schweiz. Arch. angew. Wiss. 18(9): 292-307.

8. Eisenmann, E.
   1949. Moderne holztrocknung und ihre arbeitsgrundlage, Holz-Zentralblatt 75(75): 945.

9. Fischer, W., and E. Czepek.
   1941. Die heisstrocknung von weichholz in elecktrobeheizten trockenraumen. Mitt. Fachaussch. Holzfragen, Heft 30: 46. Berlin.

10. Guernsey, F. W.
    1957. High-temperature drying of British Columbia softwoods. Forest Prod. J. 7(10): 368-371.

11. Hann, R. A.
    1964. Drying yellow-poplar at temperatures above 100° C. Forest Prod. J. 14(5): 215-220.

12. Kauman, W. G.
    1956. Equilibrium moisture content relations and drying control in superheated steam drying. Forest Prod. J. 6(9): 328-332.

13. Keylwerth, R.
    1949. Fundamentals of high-temperature drying of wood. Holz-Zentralblatt 75(76): 953-954.

14. ________
    1952. High-temperature seasoning plant. Holz a. Roh-u. Werkst. 10(4): 134-138.

15. Kimball, K. E., and D. P. Lowery.
    1967. High-temperature and conventional temperature methods for drying lodgepole pine and western larch studs. Forest Prod. J. 17(4): 32-40.

16. Knight, E.
1959. Elevated kiln temperatures for the associated species (in the western pine region). Western Pine Assoc. Res. Note 4.215, 10 pp.

17. Koehler, A.
1926. Relation of moisture content and drying rate of wood to humidity of atmosphere. U.S. Dep. Agr., Forest Prod. Lab. Rep. R.509.

18. ________ and M. Y. Pillow.
1925. Effect of high temperatures on the mode of fracture of a softwood. Southern Lumberman 121 (Dec. 19): 219-221.

19. Kollmann, F.
1954. Recent German-Swedish contributions to physics of lumber seasoning. Holz a. Roh-u. Werkst. 12(6): 213-223.

20. ________ and A. Schneider.
1961. The effect of the flow velocity on the kiln drying of timber in superheated steam. Holz a. Roh-u. Werkst. 19(12): 461-478.

21. Kozlik, C. J.
1967. Effect of kiln conditions on the strength of Douglas-fir and western hemlock. Forest Res. Lab., Oreg. State Univ. Rep. D-9.

22. Krechetov, I. V., and B. S. Tsarev.
1955. Wood seasoning by means of superheated steam. Derev. Prom. 4(12): 9-12.

23. Ladell, J. L.
1955. The role of circulation rate in high-temperature drying. Brit. Columbia Lumberman 39(10, 11): 46-50; 42-44, 68-70.

24. Leontev, N. L., I. V. Krechetov, B. S. Tsarev, and A. V. Suchova.
1956. Effect of high-temperature drying schedules on the physical and mechanical properties of wood. Derev. Prom. 5(10): 3-5.

25. Lowery, D. P., and K. E. Kimball.
1966. Evaluation of high-temperature and conventional methods of stud drying. Northwest Wood Prod. Clinic Proc., Spokane, Wash. Pp. 55-65.

26. ________ and J. P. Krier.
1966. Bibliography of high-temperature drying of lumber. U.S. Forest Serv. Res. Pap. INT-27, 14 pp.

27. MacDonald, B. F., and H. Maclean.
1965. Effect of high temperature on the durability of western redcedar. Can. Forest Ind. 85(3): 93,95.

28. Mac Lean, J. D.
1951. Rate of disintegration of wood under different heating conditions. Amer. Wood Pres. Assoc. 47: 155-168.

29. Möller and Pfeiffer.
1897. Dry kiln for superheated steam drying with exclusion of atmospheric air. German Pat. No. 100, 287.

30. Salamon, M.
1960. Kiln drying of unbundled shingles at high temperatures. Timber of Can. 21(9): 35-37.

31. ________
1963. Quality and strength properties of Douglas-fir dried at high temperatures. Forest Prod. J. 13(8): 339-344.

32. ________
1965. Effect of high-temperature drying on quality and strength of western hemlock. Forest Prod. J. 15(3): 122-126.

33. Sharma, S. N., and B. I. Bali.
1964. A study of the shrinkage of Toon (Cedrela toona) in high-temperature drying. Indian Forest. Bull. 240, 11 pp.

34. ________, B. I. Bali, and M. A. Rehman.
1962. Experiments on the high-temperature drying of some Indian timbers. II. Indian Forest Bull. 236, 16 pp.

35. Stemsrud, F.
1953. High temperature seasoning of wood. Norsk. Skogind. 7(10): 335-341.

36. Tiemann, H.
1918. Superheated steam dry kiln. U.S. Pat. No. 1, 268, 180.

37. ________
1920. The kiln drying of lumber. 2d ed., 320 pp., Philadelphia: J. B. Lippincott Co.

Lowery, David P., John P. Krier, and Robert A. Hann.
1968. High-temperature drying of lumber--a review.
U.S. Dep. Agr., Forest Serv., Intermountain Forest and Range Exp. Sta., Ogden, Utah. 10 pp. (U.S. Forest Serv. Res. Pap. INT-48)

Summarizes research results of high-temperature drying investigations. Conflicting results and areas where knowledge is incomplete or lacking are emphasized.

Lowery, David P., John P. Krier, and Robert A. Hann.
1968. High-temperature drying of lumber--a review.
U.S. Dep. Agr., Forest Serv., Intermountain Forest and Range Exp. Sta., Ogden, Utah. 10 pp. (U.S. Forest Serv. Res. Pap. INT-48)

Summarizes research results of high-temperature drying investigations. Conflicting results and areas where knowledge is incomplete or lacking are emphasized.

Lowery, David P., John P. Krier, and Robert A. Hann.
1968. High-temperature drying of lumber--a review.
U.S. Dep. Agr., Forest Serv., Intermountain Forest and Range Exp. Sta., Ogden, Utah. 10 pp. (U.S. Forest Serv. Res. Pap. INT-48)

Summarizes research results of high-temperature drying investigations. Conflicting results and areas where knowledge is incomplete or lacking are emphasized.

Lowery, David P., John P. Krier, and Robert A. Hann.
1968. High-temperature drying of lumber--a review.
U.S. Dep. Agr., Forest Serv., Intermountain Forest and Range Exp. Sta., Ogden, Utah. 10 pp. (U.S. Forest Serv. Res. Pap. INT-48)

Summarizes research results of high-temperature drying investigations. Conflicting results and areas where knowledge is incomplete or lacking are emphasized.

Headquarters for the Intermountain Forest and Range Experiment Station are in Ogden, Utah. Project headquarters are also at:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Provo, Utah (in cooperation with Brigham Young University)

FOREST SERVICE CREED

The Forest Service of the U. S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing nation.